

Agrogeomatic techniques application for a more precise management of corn (*Zea mays* L.)

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Abstract

The present study aims at defining a methodology for analysing and processing crop yields, that together with an integrate use of hardware (GPS) and software (GIS, Geostatistics) tools, will allow the acquisition, the analysis, and the cartographic representation of information for identifying isomanagement areas and optimize the agrotechniques.

In the Educational-Research University Farm “Menozzi” during the three-year (2000-2002) period a cultivated field (*Zea mays* L.) was monitored by applying geostatistics techniques for analysing the internal variability.

The georeferentiation of the soil and vegetation samples allowed to create, through appropriate spatialization techniques, yield variability maps for each year.

Thereafter, through the spatial and temporal analysis carried out by applying a methodology previously proposed, it was possible to obtain a yield map where the firmly high productive, firmly low productive and instable in time areas are clearly indicated.

These areas can be considered isomanagement areas where it will possible to evaluate a different application of agronomical production factors (water, organic matter, chemicals, labour etc.).

1. Introduction

Most of the cultivated fields present significative variability in soil parameters; part of the variability is natural, part is generated and related to agronomic practices. The complexity of the agroecosystem is due to the interactions of its spatial and temporal components (Verhagen and Bouma, 1997; Pierce and Nowak, 1999).

Notwithstanding that the agricultural crops react, as natural, in a differentiated way, the farmers consider the cultivated fields and the crops as homogeneous. This can lead, particularly for intensified and high-input systems, to a low use ef-

efficiency of the production factors, and, in turn, both to significant risks of contamination and a decrease of farmer income.

The so called Precision Farming (PF), based on the knowledge of the internal field variability, tries to decrease these risks by modulating the use of the production factors which are distributed, according to the needs, with machines equipped with Variable Rate Technology (VRT) instruments. VRT, compared to Uniform Rate Technology (URT) is considered with increasing interest for its real economical and agro-environmental advantages (Babcock and Pautsch, 1997; Baker, 1999; Ebelhar et al. 2000; Griffin et al. 2000; Whitley et al, 2000; Wang et al. 2003) and there are already many application fields (Ferguson et al. 2002; Bechdol et al. 2000; Chosa et al. 2003). Since the implementation of a PF systems requires the individuation of homogeneous areas where to apply the same management (Fleming, 2003; Walker, 2004) one of the priority of the agronomic research is the knowledge of the variability of the main soil and crop components (Bocchi et al., 2000).

The present study aims at individuating an acquisition and elaboration data process allowing the analysis and the representation of the so called isomanagement areas, so that it will be possible to plan agronomic techniques modulated both at field and landscape scale.

2. Materials and methods

2.1 Site description and field measurements

The study was carried out at Menozzi farm at Landriano (Pavia province) on the field “Bruciata” with a surface of 2.07.10 ha.a.ca. The soil and crop samples were collected in the knots of a regular grid of 5.6 x 16 m. The centres of the recovered rectangular supports were georeferenced through a DGPS.

2.2 Yield data survey

Corn (*Zea mays L.*, FAO class 600) was grown by adopting the traditional agro-techniques able to avoid the most common internal limiting factors (i.e. water, nutrients, weeds, parasites). The harvest was carried out with a combine plot threshing machine collecting the three central rows of each support 6 m length. Every year a total of 143 supports were harvested. After harvesting the yield (t/ha) was measured and was determined humidity (%) and the 1000 grains weight (g dw).

2.3 Exploratory data analysis and spatial analysis

The exploratory data analysis for each of the analysed variable and for each year included the computation of the following statistics: average, standard deviation,

variance, coefficient of variability, skewness, kurtosis. The spatial distribution of 1000 grain weight and grain yield was analysed through the study of the matrix of the experimental omnidirectional direct and cross semivariograms. The choice of the model fitting the semivariogram was carried out with an automatic procedure, by selecting previously the mathematical functions and by recovering the best one. The geostatistical analysis was carried out with ISATIS v. 5.0 (Geovariances).

2.4 Validation

The fitting process results were evaluated through Cross Validation technique. The values exceeding $2.5 (\pm 2.5)$ standard error were selected as outliers non included inside the confidential range of 95 % of the normal distribution.

2.5 Interpolation techniques

Different interpolation techniques were adopted based on the type of observed variability for improving the quality of the spatialization and representation processes. Punctual Cokriging and the Inverse Distance Weighted (IDW) were selected.

The cross semivariogram represents a measure of the joined variability between two variables, since it is obtained by halving the average of the product of the increments h related to two attributes z and z_i :

$$\gamma_{zz'}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \{ [z(x_i) - z(x_i + h)] \cdot [z'(x_i) - z'(x_i + h)] \}$$

When one or more variables are estimated as linear combination, by using both the spatial relation and the one between variables, the interpolation techniques is called cokriging. The cokriging equations are:

$$\begin{cases} \sum_{j=1}^n \sum_{\beta=1}^{n_i} \lambda_{\beta} \gamma_{ij}(x_{\alpha}, x_{\beta}) + \mu_i = \gamma_{ii_0}(x_{\alpha}, x_0) & \text{per } i = 1, \dots, n \text{ e } \alpha = 1, \dots, n_i \\ \sum_{\beta=1}^{n_i} \lambda_{\beta} = \delta_{ii_0} & \text{per } i = 1, \dots, n \end{cases}$$

The IDW interpolation method requires that the value assumed by a parameter in a not measured site is influenced by the values assumed by the same parameters in a spatial surrounding range, in inverse relation to a power of the distance between the point and its neighbours.

$$z^*(x_j) = \frac{\sum_{i=1}^n z(x_i) \cdot d_{ij}^{-p}}{\sum_{i=1}^n d_{ij}^{-p}}$$

Where $z^*(x_j)$ represents the interpolated value at the knot of the interpolation grid Z_i the known value, d_{ij} the distance between the interpolated point and the known value and p the exponent of the weight function.

2.6 Analysis of the space-time variability with GIS technique

Once produced the yield maps, the components of the variability at time and space scale were included by applying a specific methodology proposed by Blackmore and Larscheid (1997). For including the space component of the variability, the temporal trend was removed so that the normalized year-averages map was produced. The normalization was carried out separately for each temporal series by setting equal 100 the annual average and by calculating the new average among the obtained results. It was also possible to represent the temporal stability with a map showing those areas with firmly yield performance or, vice versa, with high time-variability during the considered period.

This map was generated by measuring the variation coefficient of the normalized yield values at the knots of the grid utilized for the field sampling.

The two maps, spatial trend and temporal stability, were finally combined in a sole agro-management map, by an overlaying function of the Geographic Information System software.

3. Results and discussion

3.1 Exploratory data analysis and spatial analysis

Different nested mathematical models, that is to say obtained with the sum of different spatial structures, were evaluated. Due to the evident presence of trend in the experimental variogram, it was opted for adapting the K-Bessel function. For years 2000 and 2002 the direct and crossed experimental semivariograms, calculated on three directions (0°, 45°, 90°) did not show particular differences so that a omnidirectional semivariogram was chosen. During the phase of interpolation a regular grid (1.5 x 1.5 m) able to completely cover the field was adopted.

By analysing the experimental semivariograms showed in Figure 1 and 2 it is possible to observe a good spatial structure of the considered parameters. Moreover, since they are not limited, it is possible to assume a structured variation at a larger scale than the one used for the sampling process. The results of the cross

validation confirm the goodness of the fitting by the chosen models and, in turn, the goodness of the kriging interpolation. (Table1 and Table 2)

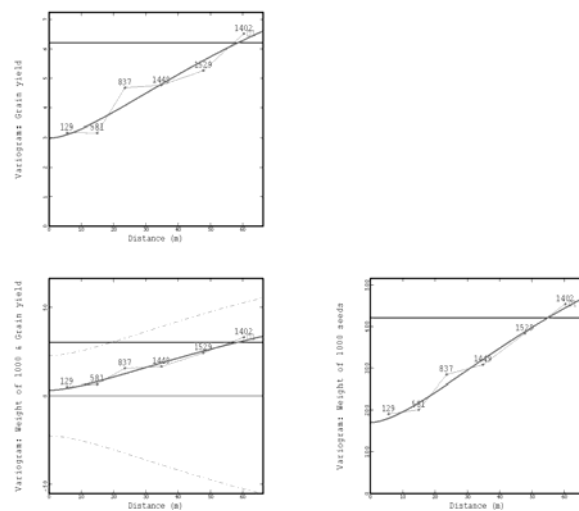


Fig. 1. Fitting of the experimental direct and crossed semivariograms year 2000

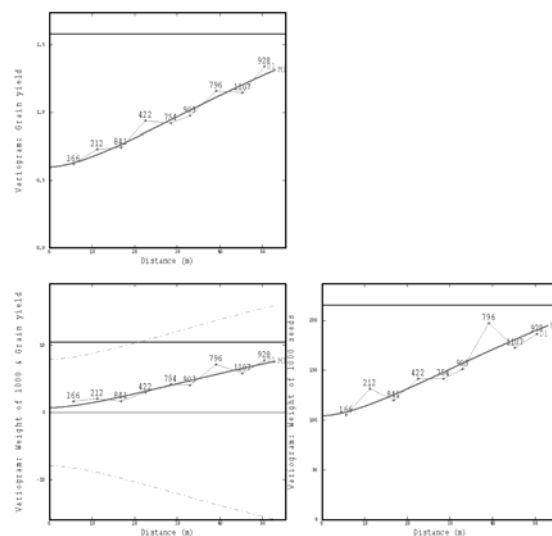


Fig. 2 Fitting of the experimental direct and crossed semivariograms year 2002

Yield grain (t/ha), 2000			Weight of 1000 grains (g), 2000		
Statistics based on 139 test data			Statistics based on 139 test data		
	Mean	Variance		Mean	Variance
Error	0.08458	3.12075	Error	0.08449	206.63348
Std. Error	0.04153	0.87960	Std. Error	-0.00701	0.99543
Statistics based on 139 robust data (*)			Statistics based on 138 robust data (*)		
	Mean	Variance		Mean	Variance
Error	0.08458	3.12075	Error	0.34950	181.94994
Std. Error	0.04153	0.87960	Std. Error	0.02351	0.87311

(*) A data is robust when its Standardized Error lies between -2.5 and 2.5

Table 1. Cross validation results for grain yield and 1000 grains weight – year 2000

Yield grain (t/ha), 2002			Weight of 1000 grains (g), 2002		
Statistics based on 139 test data			Statistics based on 139 test data		
	Mean	Variance		Mean	Variance
Error	0.08458	3.12075	Error	-0.08449	206.63348
Std. Error	0.04153	0.87960	Std. Error	-0.00701	0.99543
Statistics based on 139 robust data (*)			Statistics based on 138 robust data (*)		
	Mean	Variance		Mean	Variance
Error	0.08458	3.12075	Error	0.34950	181.94994

(*) A data is robust when its Standardized Error lies between -2.5 and 2.5

Table 2. Cross validation results for grain yield and 1000 grains weight – year 2002

For years 2001 the experimental semivariogram did not show structured variability for grain yield (Figure 3). Such result seems to be consistent to the meteorological course of the year 2001: an heavy attack by *Ostrinia nubilalis* L. was followed by a summer stormy. As it was impossible to find out structure in variation of grain yield, the IDW interpolation method was used.

The result of such interpolation is the typical so called “salt and pepper” map, where high yielding area are close to low yielding ones.

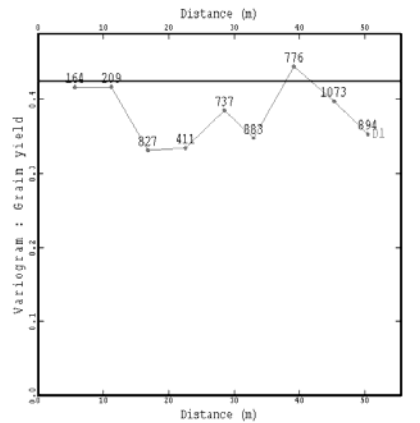


Fig. 3. Experimental variogram of grain yield (year 2001)

3.2 Spatiotemporal analysis through GIS

For better understand some of the spatial aspects of variability it was necessary to remove the temporal trend representing the yields in normalised form. The normalization was carried out separately for each temporal series (Figure 8).

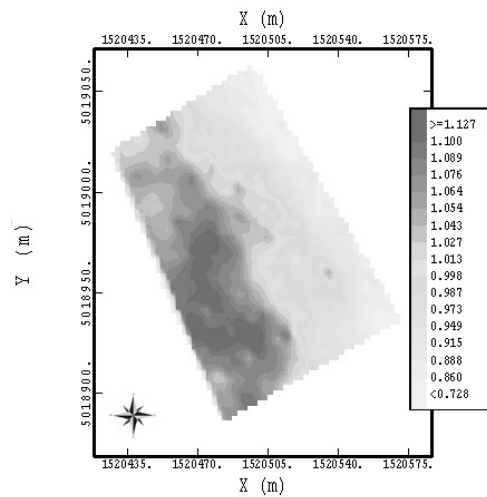


Fig. 3. Normalized grain yield map

To make easier interpreting the normalized yield map it was divided in three classes: low (normalized grain yield $<0,3$), medium ($0,3<\text{normalized grain yield}<0,6$) and high ($0,6<\text{normalized grain yield}<0,1$) (Figure 9).

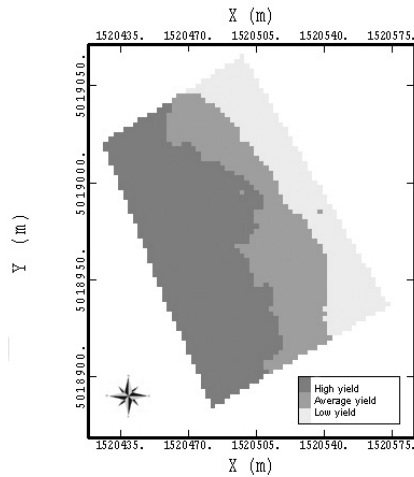


Fig. 4. Spatial trend grain yield map

The three yield data sets were also elaborated to create the temporal stability map, which identifies those areas stable or highly variable over the time period.

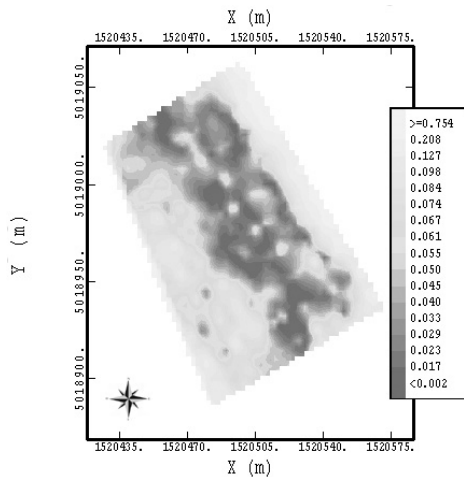


Fig. 5. Coefficient of Variation Map of the normalized grain yield

This map was produced by calculating the variation coefficient; the values of the coefficient of variation, even in this case, were classified in a limited number of classes such as unstable ($CV > 30\%$) and stable ($CV < 30\%$) (Figures 10 and 11).

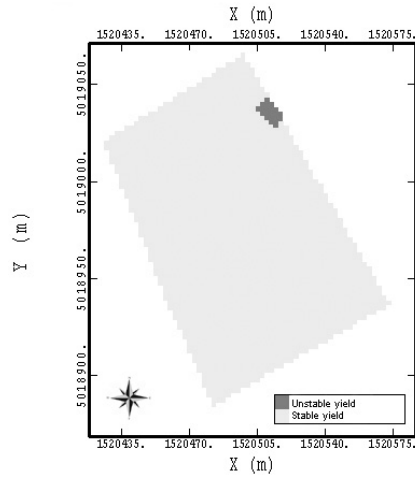


Fig. 6. Temporal stability map of grain yield

The two maps, spatial trend and temporal stability, were combined in a sole map of agronomic management, through a overlaying function of a GIS. This map allows individuating three groups of areas: those where the grain yield is significantly and firmly high over the three-year period, those where the yield is firmly low, and those where the yield level changes every year (Figure 12).

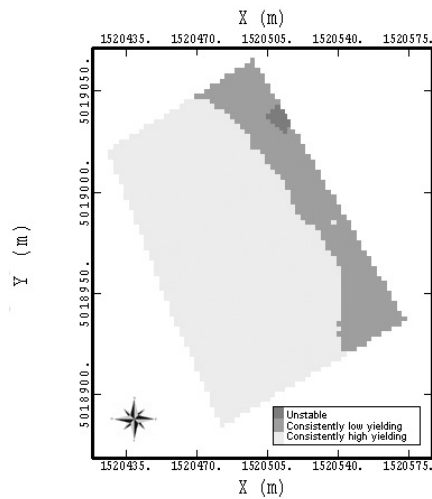


Fig. 7. Synthetic map of spatial trend and temporal stability

4. Conclusion

The results of the present study, carried out at field scale, allow observing that:

1. the grain yield, even though characterized by strong fluctuations, due to the peculiar bio-climatic conditions of the considered years, showed a good structure of variability. This structure allowed to adequately exploit geostatistics and kriging procedures in spatialization processes;
2. the spatial structure of the grain yield, maintained along the period, allowed and justify, for the interpolation and estimate, the use of the same set of functions;
3. GIS analysis allowed studying deeply, but easily the spatial and temporal components of the yield variability. The temporal component, after individuation, was removed through a de-trendization process so that it was recovered information on the yield spatial trend;
4. the combination of the two components allowed to produce a map useful to individuate limiting factors, optimize agrotechniques, reduce impacts, increase economical income;
5. with GIS technology, it is possible to create a Farm Information System or a Landscape Information System for applying the present methodology at different scales.

References

- Babcock BA, Pautsch GR (1997) Moving from uniform to variable fertilizer rates on Iowa corn: effects on rates and returns. CARD Working Paper. Center for Agricultural and Rural Development (CARD), Iowa State University, Ames, Iowa, USA. 97-WP182.
- Baker KD (1999) Yield potential and nitrogen fertilizer reduction for maize production using VRT. ASAE/CSAE-SCGR Annual International Meeting, Toronto, Ontario, Canada, 18-21 July, 1999. American Society of Agricultural Engineers (ASAE), St Joseph, USA: 1999.
- Blackmore BS, Larscheid G (1997) Strategies for managing variability. 1st European conference on Precision Agriculture. 8-10 Settembre, Warwick UK.
- Bocchi S, Castrignanò A, Fornaro F, Maggiore T (2000) Application of factorial kriging for mapping soil variation at field scale. European Journal of Agronomy. 13, 295 - 308.
- Chosa T, Shibata Y, Omine M (2003) Variable-rate technology for Japanese paddies. Proceedings of the 6th International Conference on Precision Agriculture and Other Precision Resources Management, Minneapolis, MN, USA, 14-17 July, 2002. American Society of Agronomy, Madison, 720-731.

- Ebelhar SA, Wyciskalla TD, Varsa EC, Chong SK, Indorante SJ, McCauley WM (2001) Evaluating the influence of variably applied potassium on yield variations in two Southern Illinois farm fields. Proceedings of the 5th International Conference on Precision Agriculture, Bloomington, Minnesota, MN USA, 16-19 July, 2000. American Society of Agronomy, Madison, USA. 1-16.
- Ferguson RB, Hergert GW, Schepers JS, Gotway CA, Cahoon JE, Peterson TA (2002) Site-specific nitrogen management of irrigated maize: yield and soil residual nitrate effects. Soil Science Society of America Journal. Soil Science Society of America Inc., Madison, USA. 66: 2, 544-553.
- Fleming KL, Buchlieter GW (2003) Evaluating two methods of developing management zones for precision farming. Proceedings of the 6th International Conference on Precision Agriculture and Other Precision Resources Management, Minneapolis, MN, USA, 14-17 July, 2002. American Society of Agronomy, Madison, USA. 426-442.
- Goovaerts P (1997) Geostatistics for natural resources evaluation, Oxford University Press, New York.
- Griffin TW, Popp JS, Buland DV (2000) Economics of variable rate applications of phosphorus on a rice and soybean rotation in Arkansas. Proceedings of the 5th International Conference on Precision Agriculture, Bloomington, Minnesota, USA, 16-19 July, 2000. American Society of Agronomy, Madison, USA. 1-11
- Pierce FJ, Nowak P (1999) Aspects of precision agriculture, Advances in Agronomy, Vol 67 pp 1-80.
- Verhagen J, Bouma J (1997) Modelling soil variability. In "The state of site-specific management for agriculture". ASA Miscellaneous Publication. ASA, CSSA, and SSSA, Madison, WI. pp 55-67.
- Walker T, Cox M, Kingery W, Martin S, Oldham L, Street J (2004) Defining and managing yield zones for rice and soybeans - a case study. Better Crops with Plant Food. Potash and Phosphate Institute (PPI), Norcross, USA. 88: 1, 10-13.
- Wang DC, Prato T, Qiu ZY, Kitchen NR, Sudduth KA (2003) Economic and environmental evaluation of variable rate nitrogen and lime application for claypan soil fields. Precision Agriculture. Kluwer Academic Publishers, Dordrecht, Netherlands. 4: 1, 35-52.
- Whitley KM, Davenport JR, Manley SR (2000) Differences in nitrate leaching under variable and conventional nitrogen fertilizer management in irrigated potato systems. Proceedings of the 5th International Conference on Precision Agriculture, Bloomington, Minnesota, USA, 16-19 July 2000. American Society of Agronomy, Madison, USA 1-9.